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SHORT COMMUNICATION

COMPARISON OF FISH ASSEMBLAGES AND WATER QUALITY IN TWO MARINAS IN THE BRITISH VIRGIN ISLANDS

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Introduction

Eutrophication is a widespread problem in tropical marine environments that leads to the increase of nutrients in a water body, usually nitrate and phosphate, and is usually associated with the discharge of untreated sewage, intensive farming or fertilizer-enriched agricultural runoff (Wu 1999). Common symptoms are increased N and P levels, increased macroalgal production in shallow areas, reduced dissolved oxygen, loss of seagrass and coral habitats and changes in the fish community (Hallock and Schlager 1986, Granelli et al. 1990, Valiela 1995, Hemminga and Duarte 2000). Direct chemical testing to establish pollution levels can be difficult because of sharp pollution gradients, rapid dilution effects, changing tides and currents, variable pollutant concentrations, varying pollution activities, unavailability of water quality test kits, a prohibitive range of pollutants to test for and high testing costs (Resh et al. 1995). Many of these problems can be countered with bioassessment methods that use biotic indicators to assess ecosystem integrity (Karr 1981, Noss 1990, Wright et al. 1993, Chessman 1995). Biotic indicators of pollution have several advantages over chemical methods: they are broad-ranged, detect many forms of pollution, reflect pollution history and indicate overall health of the system.

Animal bioindicators should be: 1) sufficiently sensitive to disturbance, 2) widely distributed, 3) capable of living in a wide range of conditions, 4) relatively independent of sample size, 5) easy and cost effective to study, 6) able to differentiate between natural and man-made disturbance, and 7) relevant to ecologically significant phenomena (Noss 1990). Fish meet many of these criteria and have been included in several freshwater bioassessment protocols, sometimes referred to as biological integrity indices (Larkin and Northcote 1969, Karr 1981, Karr 1990, Hughes et al. 1998). Marine fish have been widely used as indicators of coral cover and overfishing (Bell and Galzin 1984, Findley and Findley 1985, Roberts 1995, Russ and Alcala 1998), but few studies have successfully used marine fish assemblages as indicators of pollution. One reason is that it is difficult to determine the direct effects of pollution on marine fish assemblages because natural experiments are usually confounded by habitat alteration due to dredging, siltation and pollution. This study aims to assess the potential of marine fishes as bioindicators using artificial reefs as habitat controls in 2 marinas with different pollution levels.

Materials and Methods

The study was carried out in 2 marinas with high volumes of charter yacht traffic on the west end of Tortola, in the British Virgin Islands (Figure 1). Nanny Cay has berths for 180 yachts. It is a shallow bay with 2 small channels to allow water flow through the quiet backwaters of the bay, but the amount of clean water entering the bay is limited and depends on tide and prevailing currents. The bay is lined with mangroves on one side, and the substrate consists of mud covered in macroalgae but becomes sandier towards the mouth of the bay. Housing and shopping complexes line either side of the bay, and at least one bank-side housing complex discharges wastewater directly into the bay. Soper's Hole has 150 berths and is comparable in size to Nanny Cay; it is lined with mangroves on one side (Figure 1) and has a sandy substrate with some muddy areas. Sparse patches of macroalgae and seagrass dot the marina, and a deep channel between the island and the mainland allows water to flow through the bay. Several shopping complexes and housing developments line the bay, but there are no visible land-based wastewater discharges.

Ten artificial reefs were built in each bay, ranging from the more sheltered backwaters to the mouth of the bay. Rocks between 10 and 20 cm diameter were gathered from the shoreline and arranged on the substrate to form a 1m x 1m square mound, about 40 cm high. These were left for one week prior to monitoring.

Stations were visited once every week for 3 weeks in August 2002. All fish on or within 30 cm of the reef were identified and counted during a 5-minute observation period. Depth (m) was measured using a fibreglass measuring tape, and temperature (°C) was measured using a waterproof digital thermometer. Water clarity (m) was measured using a secchi disc attached to a measuring tape. One person held the disc about 30 cm below the water surface,

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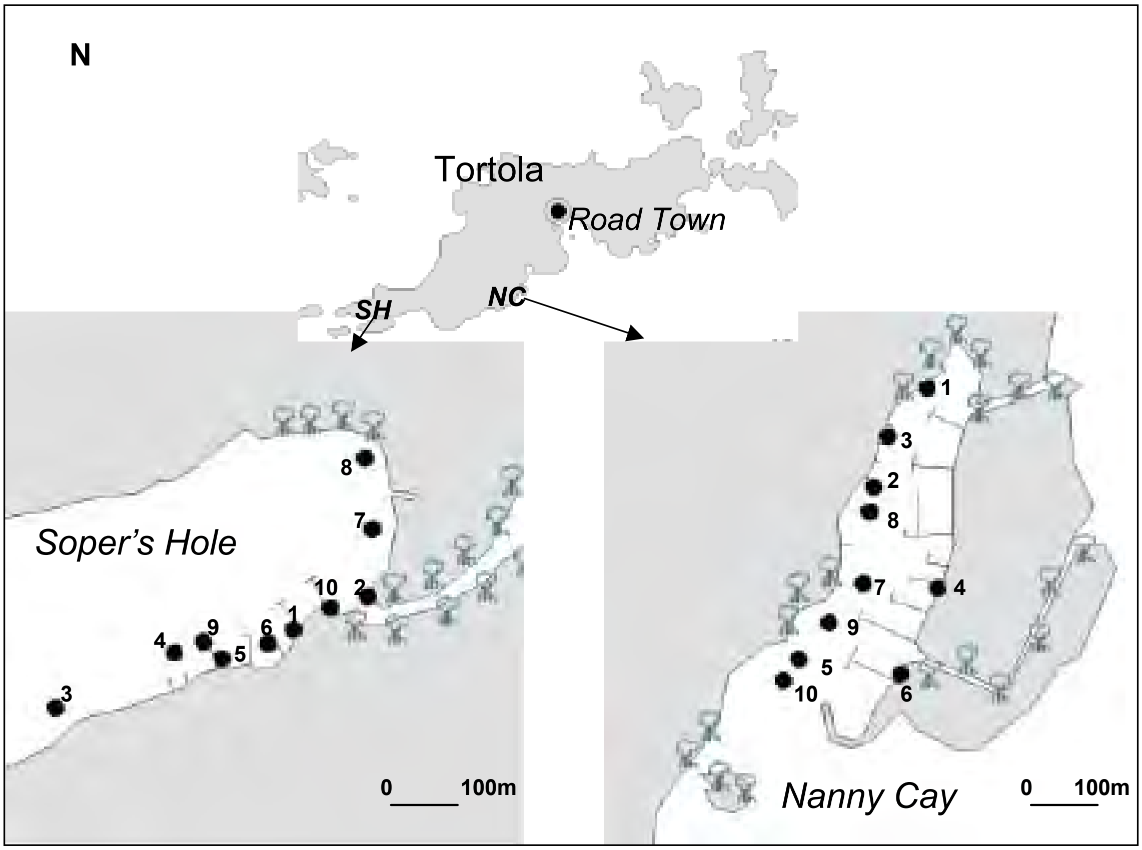

Figure 1. The location of twenty artificial reefs in the 2 marinas Nanny Cay (NC) and Soper's Hole (SH) on Tortola, an island between the Atlantic Ocean and the Caribbean Sea, west of Puerto Rico.

while the other swam away from the disc with the tape, measuring the distance at which the disc was no longer visible. Phosphate (mgl^{-1}) and nitrate (mgl^{-1}) concentrations were measured using low-range reagents and a Hach DR 850 photo spectrometer. Dissolved oxygen (DO) levels (mgl^{-1}) were measured within the first hour after sunrise each day, before oxygen levels increased due to photosynthesis, using a portable HANNA H1-9142 dissolved oxygen meter.

Differences between the mean number of fish, species richness, Shannon-Weiner diversity, depth, water clarity, DO, phosphate, and nitrate in each bay were tested using a two-sample t test; significant P values were calculated using the Bonferroni correction for multiple comparisons, dividing the standard critical $P = 0.05$ by the number of related measurements ($n = 8$)(Bonferroni 1935).

RESULTS

Nanny Cay displayed some characteristic symptoms of eutrophication: low visibility, high phosphate, and nitrate concentrations and low DO levels (Figure 2). While the absolute figures are not exceptional by global standards, they were significantly different from Soper's Hole, which was comparatively unpolluted and had higher fish species richness and abundance than Nanny Cay. The community differentiation table shows that 24 species were unique to Soper's Hole, while only 4 species were unique to Nanny Cay (Table 1).

At both stations there are water quality gradients with some stations having poorer water quality and others having better water quality (Figure 2a–h). A multiple regression model using the measured physicochemical water quality variables (but excluding visibility because of multicolinearity problems) accounted for 48% of the observed variation in fish species richness but did not explain a significant proportion of the variation in fish abundance (Table 2). In the multiple regression model, nitrate concentration was the best predictor of fish species richness, followed by phosphate concentration (Table 2).

DISCUSSION

The 2 marinas had quite distinctive fish assemblages and water quality, and these initial results indicate that fish assemblages on artificial reefs have a strong potential for

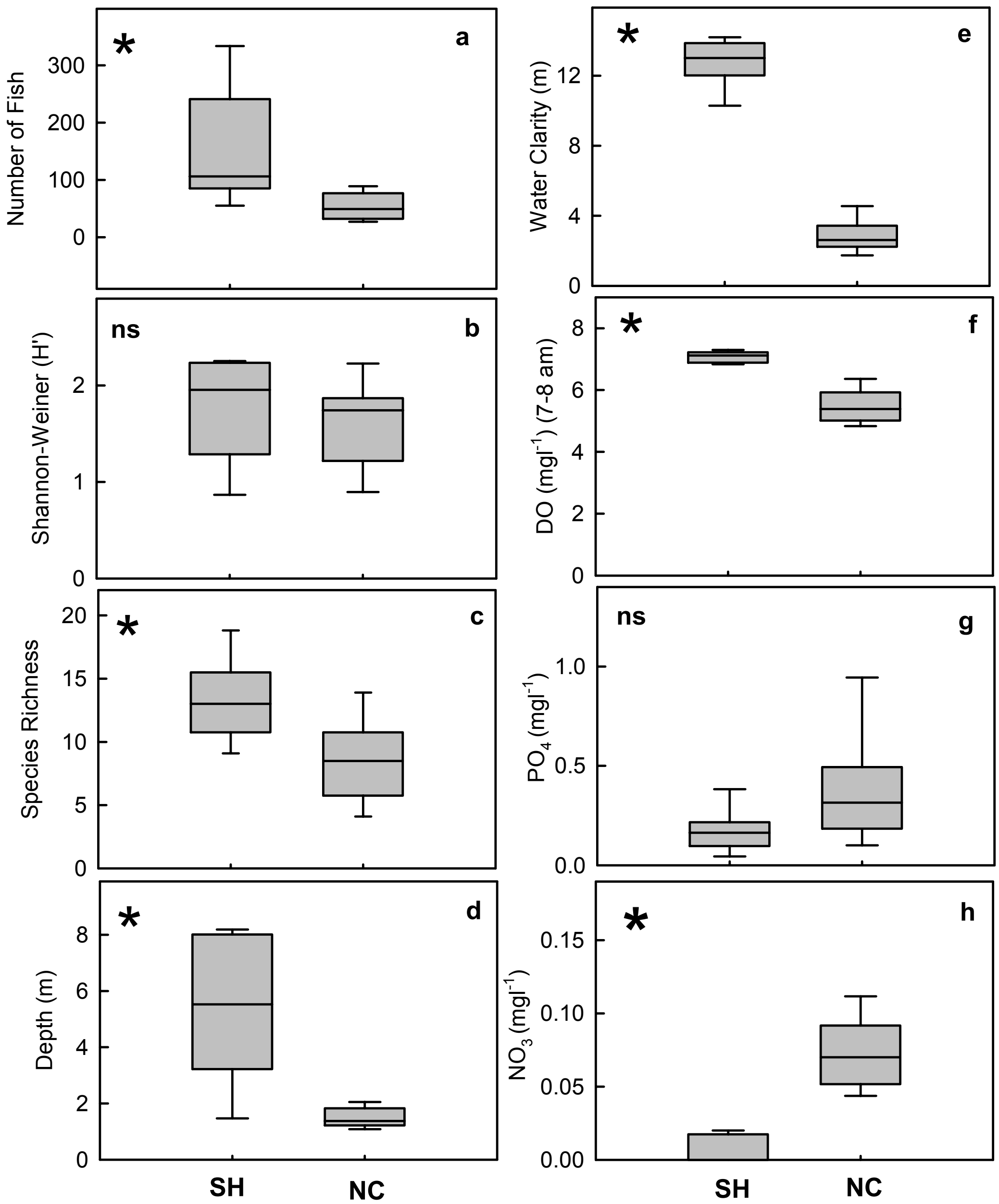

Figure 2. Boxplots illustrating the variation in biological and physicochemical variables in Nanny Cay (NC) and Soper's Hole (SH). Differences between the means were tested using a two-sample t test. * = significant difference at Bonferroni corrected *P* = 0.00625 corrected critical value.

use as biotic indicators of marine pollution. However, poor water quality is one of many factors that may have been responsible for the observed differences. For example, it is well established that proximity to other habitats, direction and strength of prevailing currents, and depth are known to affect local patterns of fish species richness and abundance (Yanez et al. 1993, Ody and Harmelin 1994, Nagelkerken et al. 2000). Because these factors were not considered, this study lacks a true control. This is a recurring problem in many environmental impact studies. One way to counter this problem is to sample a wide range of different sites, with many polluted and many unpolluted situations throughout the region to establish a wide range of validity (Wright et al. 1993). Next these data should be analysed to determine whether a typical or 'reference' state can be established which takes variation due to natural factors into account, but that can serve as valid comparisons for truly impaired stations (Wright et al. 1993, Chutter 1998).

Although such a broad survey was beyond the scope of this initial study, the gradient analysis (multiple regres-

TABLE 1

Community differentiation table of species counted on the 3 sampling occasions at Soper's Hole (SH) and Nanny Cay (NC) stations. Symbols refer to the mean abundance of that species on a logarithmic scale: · ≤ 1, • = 1–10, ● = 10–100. The order of species in the species list was determined using a TWINSPAN analysis of species (Hill 1979).

	SH1	SH2	SH3	SH4	SH5	SH6	SH7	SH8	SH9	SH10	NC1	NC2	NC3	NC4	NC5	NC6	NC7	NC8	NC9	NC10
Bothus lunatus								·												
Coryphopterus personatus								·												
Haemulon aurolineatum					●		•	•	·											
Stegastes planifrons						·														
Sphoeroides spengleri							·													
Stegastes variabilis						·														
Scarus vetula						·														
Acanthurus chirurgus									·											
Acanthurus coeruleus	•			·					·											
Calamus calamus	·									·										
Coryphopterus glaucofraenum	•	·	·	•	•	•		•	•	•										
Canthigaster rostrata	·																			
Caranx ruber				·	•	·		·	·	•										
Gerres cinereus	·																			
Hypoplectrus chlorurus									·											
Mulloidichthys martinicus									•	·										
Pseudupeneus maculatus	•				·				·	•										
Sparisoma aurofrenatum	•			·	•	·	·	•	·											
Sparisoma viride	·																			
Thalassoma bifasciatum				·																
Apogon binotatus			·																	
Clepticus parrae			·																	
Hypoplectrus puella	·	·	·	·					·	·										
Pomacanthus paru			·																	
Acanthurus bahianus	·		•	•	·	•		•	•	•	•		·		•	·				
Lutjanus synagris	•	•	●		·	●	•	•	·	•		·		·			·		·	•
Sparisoma radians		•				·	·		·	·						·				
Chaetodon capistratus	·			·		•	•		•	•		•	•	•	•	·	·			
Halichoeres bivittatus	•	•		•	•	•	•	·	•	•	·			·	·	·	·			·
Ocyurus chrysurus	•	•	●	•	•	•	•	•	•	•	·		·	•		·	·	·	•	·
Scarus iseri/taeniopterus	•	•				•	•	•	·		•		•		•	•	•	•		●
Stegastes leucostictus	·	·			·	·		·	·				·	·	•	•	·	•		
Haemulon flavolineatum		·			•		●	•	·		•	·	•	•	•	•	•		•	·
Lutjanus griseus						·		·			·	•	·	·		•		•	•	
Stegastes dorsopunicans																			·	
Sphaeroides testudineus		·					·				·									
Eucinostomus spp.		•								•	•		·	·		•	•	•	•	
Haemulon plumieri	·	·	•								·				·	•				
Abudefduf saxatilis															·					
Caranx latus																·				
Gymnothorax funebris											·							·		
Halichoeres poeyi											·									
Haemulon sciurus											•									
Lutjanus apodus											·		·		·	·	•			
Lophogobius cyprinoides													·							
Lactophrys triqueter															·					
Malacoctenus macropus		·														·		·		

TABLE 2

Multiple regression models of total number of species and total abundance of fishes observed on experimental reefs. (a) Predictor variables include nitrate, phosphate, dissolved oxygen and depth. Examination of the standardized beta coefficients revealed that only nitrate: *B* = − 0.58, *t* = − 2.27, *P* = 0.04* and phosphate: *B* = − 0.40, *t* = 2.18, *P* = 0.04* were significant predictors of fish species richness.

		Sum of squares	df	F	Sig.	Adj. r^2
Species richness	Regression	172.655	4	5.434	.007(a)	0.48**
	Residual	119.145	15			
	Total	291.800	19			
Abundance	Regression	110.378	4	2.800	.064(a)	0.27ns
	Residual	147.809	15			
	Total	258.187	19			

sion) provides suitable statistical evidence supporting the hypothesis that fish species richness on artificial habitats is indeed related to water quality, making fishes assemblages potentially useful bioindicators. The artificial reefs in the most polluted areas had the lowest fish species richness and abundance, as might be expected from a strongly eutrophic system (Deegan et al. 2002).

Because nutrients are often a factor limiting primary production in aquatic environments, increasing the nutrient budget of aquatic systems through mild eutrophication can lead to an increase in overall algal productivity that may cascade up the food chain and cause an increase in fish productivity (Larkin and Northcote 1969, Hulot et al. 2000). In severely eutrophic systems, however, the decay of nutrient-rich pollutants creates a very high biological oxygen demand leading to diel fluctuations in DO and elevated carbon dioxide levels that may make fish avoid heavily eutrophied zones (Larkin and Northcote 1969). The adverse effects of other chemicals also associated with severe eutrophication, such as ammonia, may adversely affect fish and deter them from strongly eutrophic areas. As fish respond to a wide range of water quality variables, they will be useful indicator taxa in eutrophication studies (Larkin and Northcote 1969).

TABLE 3

Mean characteristics of coastal marine waters of different trophic states from Häkanson (1994).

	Nitrate (mgl^{-1})	Phosphate (mgl^{-1})
Oligotrophic	< 0.26	< 0.01
Mesotrophic	0.26–0.35	0.01–0.03
Eutrophic	0.35–0.40	0.03–0.04
Hypertrophic	0.40+	0.04+

Nitrates were not excessively concentrated in either bay, although Nanny Cay had the highest levels, the range in NO_3 concentration of 0–0.1 mg l^{-1} was well below the 0.26 mg l^{-1} threshold described by Häkanson (1994), and both bays would hence be classified as oligotrophic, assuming there were no excessive phosphate concentrations. However, the phosphate levels in Nanny Cay ranged mostly between 0.02 and 0.09 mg l^{-1} and include the wide spectrum of marine classifications ranging from mesotrophic to hypertrophic, but mostly eutrophic (Figure 2, Table 3). Soper's Hole, however, would be classified as mostly oligotrophic or mesotrophic (Figure 2, Table 3). Other workers in the Caribbean have noted that phosphate concentrations of 0.0103–0.0111 mgl^{-1} (mesotrophic) had adverse effects on corals (Tomascik 1991).

There was a distinct gradient in fish species richness associated with the pollution gradients, with more polluted stations having fewer species, but not all species were detrimentally affected by poor water quality. In fact, mojarras apparently increased in abundance in more polluted areas, a pattern that has been noted elsewhere Gratwicke (2004). Other examples of apparently 'tolerant' fish include *Lutjanus griseus* and *Lutjanus apodus.* These 'tolerant' fish are all mangrove-associated (Chaves and Otto 1999, Nagelkerken et al. 2002) and might therefore be pre-adapted to low dissolved oxygen conditions associated with decomposing mangrove detritus. Other species are probably more sensitive to pollution and an advanced biomonitoring index might weight the presence or absence of each species according to its apparent pollution tolerance.

In conclusion, we believe that this study has 2 main achievements. First, using very inexpensive artificial reefs as habitat controls when investigating the effects of water quality on fishes in aquatic environments is an appropriate method. Second, a gradient analysis showing that 2 water quality variables were significantly related to fish species richness found on the reefs means that this method deserves more widespread testing to extend the range of validity of these results.

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